Catastrophic Impact of Red Tides of *Cochlodinium polykrikoides* on the Razor Clam *Solen dactylus* in Coastal Waters of the Northern Persian Gulf

Saeedi, Hanieh1*; Kamrani, Ehsan2; Matsuoka, Kazumi3

1- Shahid Beheshti University, Faculty of Biological Science, Tehran, IR Iran
2- Dept. of Marine Biology and Fisheries, Hormozgan University, Bandar Abbas, IR Iran
3- Institute for East China Sea Research, Nagasaki University, Nagasaki, Japan

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Abstract
A *Cochlodinium polykrikoides* red tide occurred in northern coastal waters of the Persian Gulf which killed million tons of fish and benthic animals. This study reports high mortality rate of *Solen dactylus* (razor clam) populations on the Golshahr coast of Bandar Abbas to show that management and monitoring plans are necessary to prevent future mass mortalities. Specimens of *S. dactylus* were collected during the red tide for three months in November 2008, February and April 2009. In April 2009, no clams were found in this area because all clams had died before the investigation. Abundance of razor clams showed no significant relationship with sea-surface physical and chemical factors such as sea-surface temperature, salinity, dissolved oxygen and pH (p≥0.05). Total weight of razor clams was not significantly different between November 2008 and February 2008 (p≥0.05), however, the gonad weight of razor clams in February 2009 was significantly lower than that in February 2008 (p≤0.05).

Keywords: *Cochlodinium polykrikoides*, Red tide, Mortality, *Solen dactylus*, Persian Gulf

1. Introduction
Harmful Algae Blooms (HABs) occur worldwide and pose a threat to public health and can cause great economic hardship to the coastal fishing industries from mass mortalities of shellfish and fish (Shumway, 1990). *Cochlodinium polykrikoides* red tides have led to high mortality of marine organisms (Gárate-Lizárraga et al., 2004) in many places of west Japan and the southern coasts of Korea since 1987 (Matsuoka and Iwataki, 2004) and the California Gulf, Mexico in 2000 (Gárate-Lizárraga et al., 2004). During 2008 and 2009 in the northern Persian Gulf, *C. polykrikoides* red tides killed huge quantities of marine animals. Shumway (1990) suggested that nutrient enrichment in surface water from land and upwelling of nutrient rich bottom water, hydro-meteorological changes and previous blooms of other phytoplankton species could stimulate blooms. Razor clam, *Solen dactylus*, is a sessile macro-benthic organism which lives in canals inside the sandy-muddy coasts and is widely distributed along the northern coast of the Persian Gulf (Saeedi et al., 2009). This non-migratory

* E-mail: h-saeedi@hotmail.com
bivalve is sensitive to changes of the chemical and physical factors of water. Consequently, red tides induced chemical changes in the water provide a difficult situation for these animals.

Effects of harmful algae on macro-benthic animals especially filter feeder bivalves have been widely studied. For instance, harmful algae are known to act as stressors of bivalve populations (Hégaret et al., 2007). Different aspects of harmful algae affect biology, larval development, clearance rate and behavior of bivalves. Shumway et al. (1985) and Shumway and Cucci (1987) worked on behavioral and physiological effects of the PSP-producing dinoflagellate *Alexandrium tamarense* on bivalve molluscs and determined a variety of behavioral and physiological aspects that were different in various bivalve species. Leverone et al. (2007) studied the effects of the neurotoxic dinoflagellate *Karenia brevis* on larval development and clearance rate in bivalves in Florida and suggested that blooms of *K. brevis* with particularly their associated brevetoxins, might have detrimental implications for Florida’s shell fisheries by disrupting critical larval processes. Hégaret et al. (2007) determined that different bivalves showed different responses and behaved biologically different in the presence of specific harmful algae. Da Silva et al. (2008) investigated interaction and immunological responses of the Manila clam (*Ruditapes philippinarum*) with varying parasite (*Perkinsus olseni*) burden, during a long-term exposure to the harmful alga, *Karenia selliformis* in the northwest France. Initial exposure of *P. olseni*-infected clams to *K. selliformis* modified the host–parasite interaction by causing effects in both organisms.

High mortality of clams from the Golshahr coast of Bandar Abbas, the Persian Gulf was reported (Saeedi et al., in press). This investigation was carried out to study the harmful effects of bloom on mortality of clams and to recommend monitoring phytoplankton populations to help preventing future mortalities.

2. Materials and Methods

2.1. Study Area and Sampling

Specimens of *S. dactylus* were collected during the low tide in November 2008 (start of the red tide), February 2009 (middle of the red tide) and April 2009 (during the red tide when no clams were found) along the Golshahr coast of Bandar Abbas (between Park-e-Dolat, 56° 21’ E, 27° 12’ N and Park-e-Qadir, 56° 20’ E, 27° 11/N). Razor clams were captured manually with a 0.5 m long metal wire shaped into a V at one end. All specimens were frozen after capturing. Regarding authors study on biology and metal concentrations in *Solen dactylus* from 2007-2009 all required information on other months (e.g. August 2008) has been extracted from those researches (Saeedi et al., 2009).

2.2. Data Analysis

2.2.1. Biometry and Length-Weight Relationship

Biometric factors of razor clams were measured with vernier calipers including anterio-posterior length, dorso-ventral width in 0.1 mm level and total weight (TW), wet weight of the soft parts (SPW) and gonad weight (during the reproduction) by a digital balance to 0.1 mg accuracy.

The relationship between length and the total weight of specimens was estimated in November and February by the following regression analysis.

\[
W = a L^b
\]

Where \(W\) is the total weight (g), \(L\) is the length (mm), \(a\) and \(b\) are constants (Park and Oh, 2002). A t-test was used to compare differences of the total weights for the same length classes between November 2008 and February 2009.

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Macrobenthic animals are sensitive to changes of environmental factors such as oxygen reduction and temperature stresses which can reduce the reproduction activity and gonad weight. For this reason, the mean of gonad weight for 6 length classes was determined in February 2009 and compared to the mean of gonad weight in February 2008 (Saeedi et al., 2009) and paired-
samples t-test was used to determine the differences of gonad weight before and after the red tide.

2.2.2. Environmental Data Analysis

Sea-surface temperature, salinity, dissolved oxygen, and pH were measured in three different months during the low tide and compared to these data of the sea-surface taken by Saeedi et al. (2009). The Pearson Correlation Test was used to determine correlations between sea environmental factors and abundance of clams.

3. Results

3.1. Effects of the Red Tide on Production and Weight of S. dactylus

Sampling was undertaken in three months during the C. polykrikoides red tide on the Golshahr coast of Bandar Abbas along the Persian Gulf. Figure 1 shows abundance of razor clams in different tidal zones during the red tide. Abundance of individuals decreased from November 2008 to April 2009. In November 2008, a few months after the outbreak of the red tide, abundance of the clams was lower than in August 2008 (Saeedi et al., 2009). In February 2009, 5-6 months after the red tide, a sharp decrease occurred in abundance of clams. Furthermore, most of the clams were spent and found on the coast out of their burrows. Many dead clams which surfaced to the coast from their burrows were observed. In April 2009 (7-8 months after the red tide), no clams were found in none of the tidal zones in the sampling areas.

Total weight of the different length classes between November 2008 and February 2009 were not significantly different (t=0.05, df=24, p≥0.05) (Fig. 2). The mean of gonad weights in February 2009 was significantly larger than that of February 2008 before the incidence of the red tide (t=4.40, df=5, p≤0.05) (Table 1).

3.2. Effects of the Red Tide on Sea-Surface Physical and Chemical Factors

Sea-surface physical and chemical factors fluctuated before and after the occurrence of the red-tide (Table 2). No significant correlation was found between the production of razor clams and factors such as temperature, salinity, dissolved oxygen and pH from August 2008 to April 2009 (p≥0.05).
Table 2. Sea-surface physical and chemical measurements from April 2007 to April 2009 in coastal waters of Bandar Abbas.

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (°C)</th>
<th>Salinity (psu)</th>
<th>Dissolved Oxygen (in afternoon) (mg/l)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 2007</td>
<td>22</td>
<td>38</td>
<td>6.1</td>
<td>8.3</td>
</tr>
<tr>
<td>November 2008</td>
<td>27</td>
<td>36.6</td>
<td>5.9x</td>
<td>7.8</td>
</tr>
<tr>
<td>February 2007</td>
<td>22.5</td>
<td>38</td>
<td>6.3</td>
<td>8.2</td>
</tr>
<tr>
<td>February 2009</td>
<td>23</td>
<td>37.2</td>
<td>5.8</td>
<td>7.6</td>
</tr>
<tr>
<td>April 2007</td>
<td>32.5</td>
<td>39.5</td>
<td>5.9</td>
<td>8.5</td>
</tr>
<tr>
<td>April 2009</td>
<td>33</td>
<td>38.4</td>
<td>5.6</td>
<td>7.3</td>
</tr>
</tbody>
</table>

4. Discussion

4.1. Environmental Conditions of Bloom

*C. polykrikoides* is an unarmored marine dinoflagellate that can grow in suitable conditions like high concentrations of nutrients, wind and rain stress at temperatures of 29-31 °C and salinities of 28.94-32.5 psu (Garate-Lizárraga et al., 2004). Yamatogi et al. (2002) demonstrated that temperature and salinity are two important factors for growth of *C. polykrikoides* and the maximum growth rate of *C. polykrikoides* was at 27.5 °C and 32 psu. This range of temperature and salinity is concordant to those of the study area in the Persian Gulf. After the Guno cycle in late June 2007, algal blooms in the Oman Sea were observed (Wang and Hui, 2008). In addition to nutrient enrichment, high temperature and salinity had triggered previously similar to the red tide blooms (Shumway, 1990).

4.2. Toxic Mechanism by *Cochlodinium* Blooms

Some algal blooms may produce toxins or cause anoxia. *C. polykrikoides* is known to generate reactive oxygen radicals which can contribute to kill fish and shellfish (Garate-Lizarraga et al., 2004; Jeong et al., 2004). However, no evidence exists that reactive oxygen radicals from *C. polykrikoides* can cause large mass molarities of fish and shellfish (Matsuoka et al., 2010). Anoxia can also have negative effects on filter-feeding bivalves, which are sensitive to low dissolved oxygen and decrease the clearance rate (Leverone et al., 2007). Razor clams are known to be sensitive to oxygen reduction (Saeedi et al., 2009), by *C. polykrikoides* red tides by bacterial activity at the end of the bloom. Such oxygen depression can cause mass mortality at nighttime particularly (Saraji, 2010).

Furthermore, *C. polykrikoides* is known to secrets cyto-toxic agents and mucus substance that can kill various marine animals by clogging their gills (Garate-Lizarraga et al., 2004; Kim et al., 2008; Matsuoka et al. 2010). Sellner et al. (1995) stated that juvenile *Crassostrea virginica* fed on dinoflagellates *Prorocentrum mariae-lebouriae* (= P. minimum) and *Gyrodinium uncateunum* (= *Gymnodinium uncateunum*) and transfer surface bloom production to the sediments as feces and pseudofeces which increase benthic oxygen demand and convey dominant oxygen demand from the pelagic to the benthic environment in Chesapeake Bay. Some pelagic and epi-benthic marine organisms feed on *C. polykrikoides* and increase oxygen demand by producing feces in the benthic environment where specimens of *S. dactylus* is living. Shumway et al. (1985) determined that *A. tamarense* bloom could have different effects on various species of shellfish including changing their oxygen consumption rates, heart rates and filtration rates. Accordingly, further studies on filtration rate and oxygen consumption of these razor clams are necessary in order to clarify their response to *C. polykrikoides* blooms.

4.3. Persian Gulf Observations

In November 2008 specimens of *S. dactylus* were less abundant before the red tide, but they were still present in their burrows, whereas in February 2009 razor clams were under pressure from the red tide incidence and most of them left their burrows. *C. polykrikoides* is a mixotrophic species which can
ingest small phytoplankton ≤ 11 μm (Jeong et al., 2004). It suggests that this species may consume juvenile clams and alternatively adult S. dactylus can eat C. polykrikoides; however, no weight reduction of razor clams occurred between November 2008 and February 2009.

Razor clams were in the reproductive cycle in February and a slight increase of gonad weight could be the main reason of the absence of significant weight differences between November 2008 and February 2009. Razor clams before entering to the reproductive cycle save energy for reproduction. Specimens of S. dactylus loose energy to withstand the unfavorable conditions during the red tide. For this reason, these clams could not reproduce normally and their gonad weights decreased. In fact, specimens of S. dactylus preferred to consume their energy to survive.

There was no significant relationship between abundance of razor clams and sea-surface physical and chemical factors before and after the red tide. Dinoflagellate blooms can change chemical condition of the water (e.g. dissolved oxygen) and future studies accurately determine water chemical changes and their effect on clams’ mortality. During the red tide dissolved oxygen sharply declined at night (Saraji, 2010), whereas in the morning and afternoon (the time of water quality measurements of this study) do not significantly differ from that of the pre red tides. C. polykrikoides is a photosynthetic organism which produce oxygen from the morning, whereas oxygen is consumed by marine organisms intensely at night.

Some staff in the Fisheries Research Center in Bandar Abbas reported that most mass mortalities occurred in the morning (Saraji, 2010). High decrease of dissolved oxygen at night may be the important reasons of high mortality in the morning. In conclusion, for preventing future blooms which can importantly affect marine natural and cultured organisms, monitoring plans, management programs and researches like determination of chlorophyll a levels and control emissions of sewage and urban wastes into water bodies are highly recommended.

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